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United States  
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NWRC 92-3

October 1992

Presenting the Climate and Hydrology Research  
Component of the Agricultural Research Service  
Global Change Research Program

# Global Change, Water Resources and Agriculture



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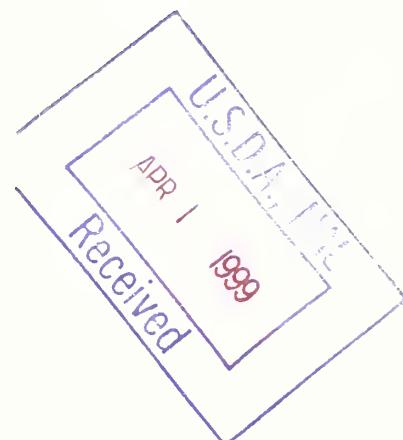
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# Global Change, Water Resources and Agriculture



**Wilbert H. Blackburn and Gregory L. Johnson, Editors**

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Front Cover: Spatial variability of snow cover, Reynolds  
Creek Experimental Watershed, Idaho



## Preface

The issue of global change will undoubtedly be a significant one for many years. It is now evident that it may be several years or even decades before conclusive evidence of human-induced global climate change is brought forward. There are significant hints that this is already occurring, though, and the implications of such change are enormous. Regardless of the degree of change, variability in climate and all other earth systems is a fact of life. Understanding variability in the hydrologic sphere is of special concern, since water is certainly foundational for life on this planet. Documenting and comprehending variability today and in the recent past is essential to developing accurate predictive models capable of estimating ecosystem response to global change. By utilizing such models, strategies for preparing for and adapting to potential change can then be prepared. To these ends this research plan is dedicated.

The following report represents the efforts of many individuals within the U.S. Department of Agriculture's Agricultural Research Service who are actively involved in global change research, particularly as it relates to climate and hydrology. This working document is the fruition of several years of planning, which culminated with a meeting in Denver, Colorado in January of 1992. At that meeting individuals from each of the research units represented in this document collectively developed the specific objectives and tasks that are outlined herein. These objectives target key areas of research within the hydrologic community where significant knowledge gaps still exist — gaps which must be filled before answers to specific global change questions can be determined.

This research plan is the direct result of the significant efforts over more than a two year period by the USDA-ARS research planning committee on global change and water resources. Members of the committee were Will Blackburn, Donn DeCoursey, Dave Farrell, Al Rango, Steve Rawlins, Clarence Richardson, Frank Schiebe, and Dave Woolhiser.

Special thanks go to Sue Antonich for assistance in the preparation of this document and her efforts on the global change research plan throughout its history.

Each of the participants in the global change meeting plus others involved in the planning process are thanked for their contributions to this effort. Ultimately, the research results from these endeavors will be the real measure of worth to the scientific community and the public at large.

Wilbert H. Blackburn, Co-editor  
Gregory L. Johnson, Co-editor

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**Special thanks to the individuals involved in the Global Change Research Program:**

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## Executive Summary

### Introduction

Global change promises to be one of the central environmental issues of the 21st Century. Industrial and land management activities during the past two centuries have affected the Earth's environment by increasing the quantity of carbon dioxide and other gases in the atmosphere. These gases absorb energy that would otherwise be lost to space, thus warming the Earth's environment. Global warming could have dramatic effects on atmospheric processes that affect regional weather patterns which in turn, control the health and productivity of ecological systems. In addition to its potential effect on the global energy budget, increased carbon dioxide will also influence the water and carbon budgets of terrestrial ecosystems through its effect on plant growth.

Changing weather patterns and atmospheric composition will alter the flux of energy, water and gases to the atmosphere, and influence plant distribution, water resources, and the productivity of managed ecosystems (cropland, rangeland and forestland). Lack of understanding of the linkages between atmospheric and ecosystem processes is a substantial barrier to predicting the impact of future changes in global climate.



**Figure 1.** Infrared geosynchronous satellite image of an intense Midwestern cyclone and associated cold front.

The Nation's croplands, rangelands and forests are basic to our national security and a strong national economy. These ecosystems must be managed to sustain global environmental quality, productivity, health and diversity. To effectively address the major challenges of a growing population, agriculture requires accurate predictions of the future global environment.

### ARS Expertise

The Agricultural Research Service (ARS) is the world's largest single source of scientific expertise in agriculture. ARS facilities and personnel provide a sound foundation for development and transfer of technology to address agricultural problems of national concern. ARS maintains experimental sites at locations that have records of vegetation, soil, and water and energy flux, some exceeding 50 years. The agency is a leader in development and application of physically-based models for agricultural and rangeland systems.

The ARS will provide a sound scientific basis for regional, national and international management and policy decisions regarding cropland and rangeland ecosystems in the context of the global change issue. This report documents the components of the ARS Global Change, Climate and Hydrology Research Program specifically targeted to meet the needs of the U.S. Global Change Research Program (US/GCRP).

The Agricultural Research Service-Global Change, Water Resources and Agriculture (ARS-GCWRA) program is designed to address problems of national concern that relate to: The exchange of water and energy to, within and from managed ecosystems; how these processes will be affected by changes in land cover (soil, vegetation and snow); and the interactions of climate and land-surface hydrology. A thorough and predictive understanding of these processes will be used as a resource for policy decisions related to a wide range of questions concerning environmental and economic issues that include:

- **Atmospheric warming.** How temperature, precipitation, soil water and extreme weather conditions such as droughts and floods will be affected by atmospheric warming.
- **Water supplies.** How the rate and degree of climate change will affect the future availability of adequate water supplies.

- **Food security.** How events such as drought will impact crop and forage yields and world food supplies.

Research results from this program will provide linkages between General Circulation Models (GCM's) and terrestrial climate and hydrologic processes, and can be used to develop mitigation strategies to respond to global change impacts on water supply, and the productivity of managed ecosystems. The ARS has coordinated the development of this program with other federal agencies within the Committee on Earth and Environmental Sciences (CEES) Global Change Research Program. This research program is consistent with the priorities established by CEES. The ARS has participated in the U.S. Global Change research Program planning process, and this research plan includes priorities identified within it. This report shows the specific linkages between the ARS-Global Change Research Program and the US/GCRP, and provides a broad description of the scientific efforts being conducted by the ARS to carry out its share of the global change, climate and hydrologic research.

This research program builds on the unique expertise, facilities and related research programs in ARS. The program is designed to complement, enhance and profit from other federal agencies' global change programs.



**Figure 2.** Flume measuring an ephemeral runoff event, Walnut Gulch Experimental Watershed, Arizona.

## Rationale

The Earth has always been and will continue to be a place of change. In the past, changes in the natural conditions which control the Earth's environment have caused ice ages to develop, sea levels and land surfaces to rise and fall, volcanoes to erupt and forests, deserts and grasslands to change in size, shape and composition. We need only look back a decade for examples of climatological variations that have resulted in droughts, floods, cold winters and hot summers. In addition to natural changes of the Earth and its climate, there is increasing concern that industrial activity during the 19th and 20th centuries has increased atmospheric levels of carbon dioxide and other gases that absorb the sun's energy and warm the Earth's environment by the so-called greenhouse effect.

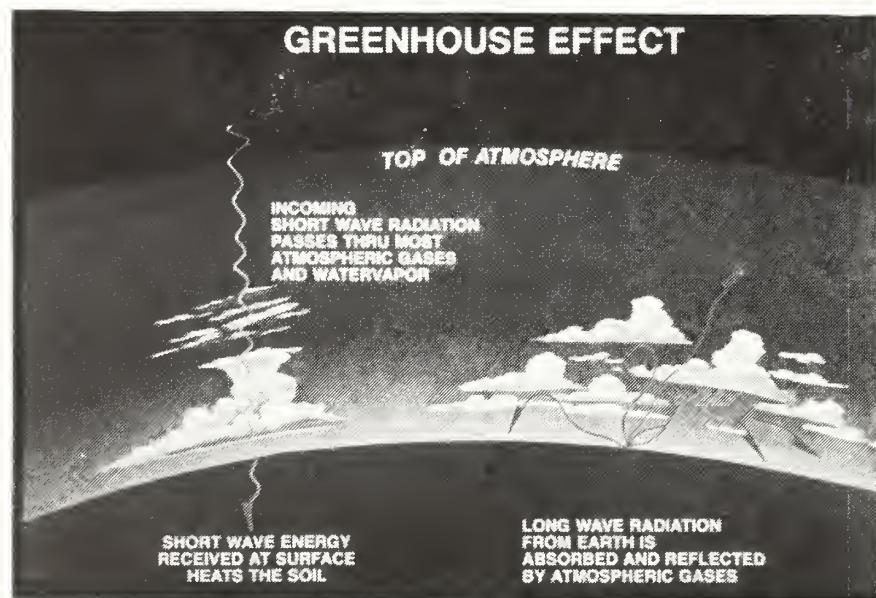
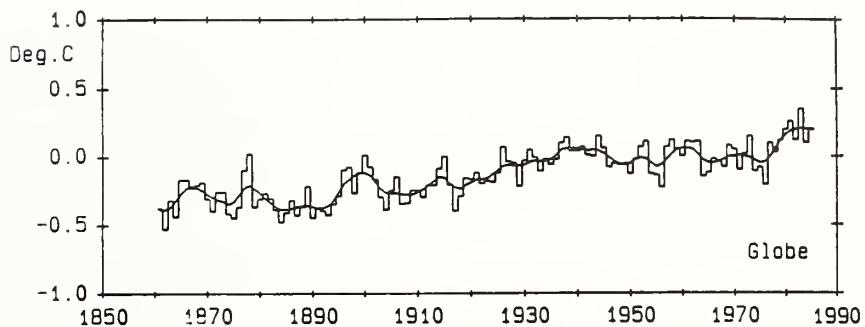


Figure 3. Diagram of the Earth's atmospheric greenhouse effect.

Nitrogen and oxygen are the main constituents of the Earth's atmosphere, and water vapor is the most important greenhouse gas. The concentrations of these constituents are stable but concentrations of other greenhouse gases are increasing. Carbon dioxide concentration is 25% greater, nitrous oxide 19% greater and methane 100% greater than before the industrial revolution. Chlorofluorocarbons (CFC's) are greenhouse gases that were completely absent before the industrial age. CFC's are a class of synthetic chemicals that also are strongly implicated in thinning

the ozone layer, allowing increased amounts of ultraviolet radiation to reach the Earth's surface. Stratospheric ozone depletion causes a change in solar heating rates that affect global temperature.

Current estimates from historical records indicate that the average global temperature has increased between 0.3 and 0.6°C since the late 19th century. No conclusive evidence exists linking this warming to the greenhouse effect, but circumstantial evidence has convinced many scientists that it is the cause. Predictions of future climate derived from General Circulation Models (GCM's) indicate that an increase in global temperature of between 1.5 and 3.0 °C could occur by the middle of the 21st century as a consequence of greenhouse gas emissions.



**Figure 4.** Global temperatures since 1860 from work by Jones et al. (*Journal of Climate and Applied Meteorology*, 1986).

Concentrations of these gases, however, are not the only factors determining potential climate change. GCM's now being used to predict future climates do not include cloud effects, nor do they fully couple the processes that take place in the oceans and on the land surface with the atmosphere. Recent measurements indicate that the structure and abundance of clouds are also changing as a result of sulfur compound emissions. Although there is little disagreement in the scientific community that changes in surface temperature of the Earth will occur, inclusion of cloud effects in GCM's may modify earlier predictions of temperature increases.

Although global change is relatively new to scientific investigation and many aspects are uncertain, there is a growing concern that greenhouse gas emissions will impact human well-being and the

quality of life through ozone depletion, global warming, sea level change, drought, desertification and reduction in biodiversity.

Climate change could significantly alter the spatial and temporal distribution of precipitation worldwide, potentially reducing both the quantity and quality of water resources, and the productivity of managed ecosystems. Several studies have indicated that water resources in some regions of the United States are vulnerable to climatic change. Although regional estimates of climate change are highly uncertain, an average increase in global temperature of several degrees Celsius could result in changes in atmospheric circulation patterns that would significantly change precipitation in certain climatic regions, leading to changes in streamflow and soil water storage. Other assessments have emphasized the likelihood of increased variability in precipitation, which would increase the frequency of droughts and floods.

Although greenhouse gas effects on global climate are of major concern to society, an increase in atmospheric carbon dioxide may also have beneficial effects on plant growth. Carbon dioxide is the basic raw material from which all living material is derived through the process of photosynthesis. Increasing its concentration, however, does not enhance photosynthesis equally for all species. A disparity between species' response to carbon dioxide could affect the structure, function and productivity of all ecosystems. It is possible that today's agriculture has already benefitted from a carbon dioxide fertilization effect, but definitive data are not yet available to substantiate this. Some crops have nearly doubled in yield in response to doubling the carbon dioxide concentration. This research has been conducted under conditions of unlimited water and nutrients. Extending these observations to full season crop production for major agricultural production regions will require additional research, as well as better predictions of regional environmental patterns.

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## **ARS's Relationship with the United States Global Change Research Program and the Committee on Earth and Environmental Sciences**

The US/GCRP has been developed, under the direction of Science and Technology Policy in the Executive Office of the President, through the CEES of the Federal Coordinating Council on Science, Engineering and Technology. The CEES is charged with developing the US/GCRP in cooperation with the National Academy of Sciences, the International Council of Scientific Unions' International Geosphere-Biosphere Program, and the World Meteorological Organization's World Climate Research Program. The CEES has established the following overall objectives for the US/GCRP:

- Establish an integrated, comprehensive, long-term program of monitoring the Earth System on a global scale;
- Conduct a program of focused studies to improve our understanding of the physical, geological, chemical, biological and social processes that influence Earth system processes and trends on global and regional scales; and
- Develop integrated conceptual and predictive Earth System models.

The CEES science program is organized around these scientific objectives with the addition of assessments. This structure helps to promote interdisciplinary interactions within the research program. There are currently eight science elements:

- Climate and Hydrologic Systems
- Biogeochemical Dynamics
- Ecological System and Dynamics
- Earth System History
- Human Interactions
- Solid Earth Processes
- Solar Influences
- Economics

The ARS-GCRP is within the US/GCRP's Climate and Hydrologic Systems, Biogeochemical Dynamics, and Ecological Systems and Dynamics science elements. The research described in this document focuses on the Climate and Hydrologic Systems Element (ARS-GCWRA). ARS locations addressing this Unique Abilities of element include the Northwest Watershed Research Center in Boise, Idaho; the Hydrology Laboratory in Beltsville, Maryland; the National Agricultural Water Quality Laboratory in Durant, Oklahoma; the Southwest Watershed Research Center in Tucson, Arizona; the Grassland, Soil and Water Research Laboratory in Temple, Texas; and, the Great Plains Systems Research Center in Ft. Collins, Colorado. The goal of the US/GCRP is to gain a predictive understanding of the interactive physical, geological, chemical, biological and social processes that regulate the total Earth System. Preliminary models have been developed for the ocean and atmosphere but not for the land. The objective of the ARS program is to develop a comprehensive model for the land-based biosphere component of the Earth system as a means of understanding how both natural and human-induced processes will affect future environmental changes, as well as to provide the basis for designing response strategies that secure continued productivity and health of the human life-support system.

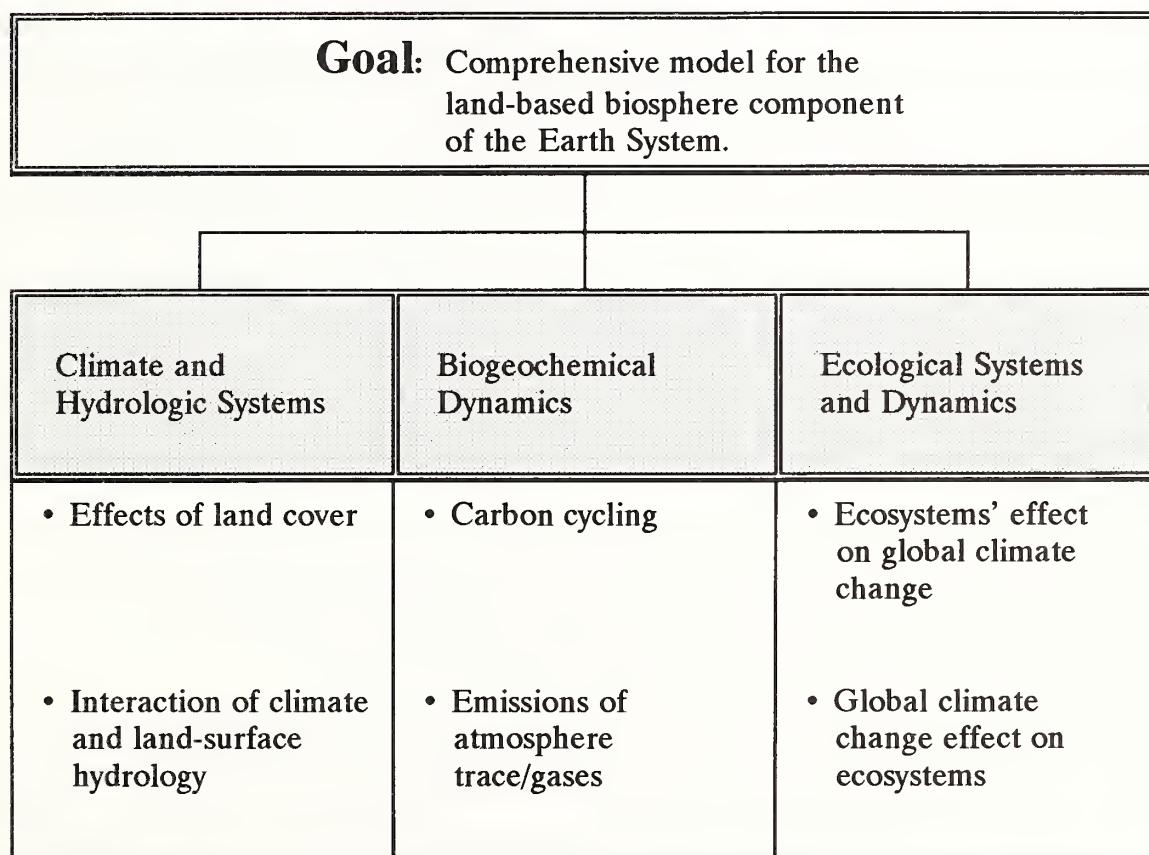
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## **The ARS Mission, Role and Science**

The mission of ARS is to develop new knowledge and technology needed to solve technical and agricultural problems of broad scope and high national priority. ARS research focuses on ensuring adequate production of high-quality food and agricultural products to meet the nutritional needs of the American consumer, sustaining a viable food and agricultural economy, and maintaining a quality environment and natural resource base. As the in-house research arm of the USDA, ARS has primary responsibility to: 1) provide initiative and leadership in agricultural research; 2) conduct research on broad regional and national agricultural and related problems; 3) conduct research to support the Federal action and regulatory agencies; 4) provide technical expertise to meet national food, safety and environmental emergencies; and, 5) serve as an agricultural science resource to executive and legislative branches. Cooperative research by ARS with state and industrial scientists is encouraged as an efficient means for increasing the overall benefits that accrue from public investments in agricultural research.

## **Unique Abilities of ARS**

The ARS provides the unique ability to perform long-term research, respond to stable and changing technical goals, focus research on gaps in knowledge that are barriers to problem solution, and perform high-risk research. ARS has an organizational structure that ensures research program accountability and coordination and the capability to form and coordinate interdisciplinary, multi-location research teams from a large, diverse scientific work force of over 2,600 highly qualified research scientists. Expertise within the scientific staff working in the ARS-GCRP includes agricultural, environmental and engineering, hydrology, mathematics, meteorology, physics, and plant and soil sciences. It encompasses both applied and basic research, and is a mix of modeling and experimentation that builds on the synergism of both methods.



**Figure 5.** Components of the ARS Global Change Research Program (from ARS Six Year Implementation Plan, 1992-1998).

## **Program Elements, Objectives and Tasks**

The premise of ARS-GCWRA is that an increased scientific understanding of the spatial and temporal variability of the hydrologic cycle over a broad range of scales will enhance our knowledge of the earth as an interconnected system, and that this knowledge will strengthen our ability to quantify changes in hydrologic variables which affect present and future ecosystem behavior.

The research approach will be interdisciplinary and will be coordinated with related global change programs in other agencies. The ARS has already established scientist-to-scientist cooperative relationships with researchers in DOE, NASA, NCAR, USDA/FS, USDA/SCS, USDC/NOAA, USDI/BLM, USDI/BOR, USDI/USGS, and in several foreign countries; e.g., England, France, Israel and Switzerland.

The first program element focuses on understanding and predicting spatial and temporal hydrologic responses over a range of scales up to 10,000 square kilometers. This is one of the most important unresolved issues in hydrology. The second program element addresses the hydrologic effects of potential global change on agriculture and will identify potential mitigation and adaptive strategies for agriculture. The following are descriptions of both ARS-GCWRA program elements, including general approaches that will be taken, objectives within each element and specific tasks, primary ARS locations where the research will be conducted:

### ***Program Element I:***

Improve predictions of water and energy fluxes to, within and from managed ecosystems by incorporating physically-based components that account for spatial, temporal and scale influences into models.

**General Approach:** The ARS will improve hydrologic and natural resource models to analyze the influence of radiation and atmospheric carbon dioxide and other greenhouse gases on water and energy transfer controlling the interactions among climate, plant-water use, surface and subsurface water movement, and streamflow. Procedures will be developed to predict precipitation regime and snowpack accumulation and melt as the consequence

of changes predicted by GCM's. This research will address the critical problem of scale in modeling terrestrial hydrologic and atmospheric processes and their interactions at point, plot and watershed scales (less than one meter to 10,000 square kilometers). Model improvements will be accomplished by coupling additional field research with new modeling approaches, and expanding cooperative efforts with other federal agencies. Data from ARS experimental watersheds, National Weather Service (NWS) precipitation stations and Soil Conservation Service (SCS) long-term precipitation and snow accumulation records will be used to modify, develop and validate models which predict the effects of global change on all aspects of the hydrologic cycle. This process will involve an evaluation of the applicability, limitations and performance of various ARS hydrologic models under a variety of conditions. In concert with model development and improvement, new concepts will be incorporated into models, taking advantage of recent advances in the use of meteorological and remotely sensed data (including doppler radar, mesoscale atmospheric model output and quantitative precipitation algorithms) and geographic information systems. Since watershed processes integrate the effects of numerous factors over a range of scales, the identification of specific water and energy flux controls at different scales will provide information regarding the relative importance of model process components.

### **Objective 1:**

Analyze and interpret scale effects of hydrologic and atmospheric processes, taking into account spatial and temporal variability.

#### **Rationale:**

The growing understanding of the importance of scale in hydrology and land atmosphere interactions suggests that the traditional modeling approach based on point relationships needs to be replaced by an approach that deals with hydrologic and physical processes and their relationships across a range of scales. Current models do not adequately account for spatial and temporal variations in model parameters and input variables. Accounting for scale and variability effects is imperative to assess and interpret possible climatic impacts from the farm scale to the sub-continental basin scale.

### **Tasks:**

1. Develop a method for characterizing the areal and temporal variation of snow covered area and snow water equivalent under changing conditions during accumulation and ablation periods. Techniques using digital terrain, remotely sensed and conventional point data will be employed (Boise and Beltsville).
2. Test the temporal stability hypothesis for soil water (Boise and Durant).
3. Quantify runoff generation and identify dominant hydrologic processes over a range of scales (Boise and Tucson).
4. Separate the spatial and temporal influence of atmospheric, soil and vegetation processes on energy and water balance (Boise, Temple, Durant, Tucson and Beltsville).
5. Develop and evaluate methods of aggregation and disaggregation of hydrologic processes and variables over a range of scales (Durant, Tucson and Beltsville).
6. Characterize spatial and temporal changes in input parameters caused by management practices — tillage, crop, canopy and residue (Ft. Collins and Durant).
7. Determine the appropriate time and space scales (resolution) and topographic watershed representation using new technologies to model water and energy fluxes over a range of basin scales and climatic zones (Durant and Tucson).

### **Objective 2:**

Utilize new technologies for parameter estimation and system evaluation of hydrologic and atmospheric models.

### **Rationale:**

Large scale, physically based hydrologic-atmospheric models require extensive data sets for parameterization and output validation. Current measurement methodologies are usually point based and are uneconomical to apply on a large scale. A new approach utilizing remote sensing and geographic

information system technologies and energy flux measurements has the potential to provide cost effective means of parameterization and output evaluation.

#### Tasks:

1. Incorporate new technologies (geographic information systems, remote sensing, etc.) into a new generation of hydrologic models (Beltsville and Durant).
2. Collect, process and analyze remotely sensed and conventional water and energy flux data in basin scale field experiments (Boise, Durant, Beltsville and Tucson).



**Figure 6.** Synthetic Aperture Radar (SAR) image of Reynolds Creek Watershed in southwest Idaho taken from NASA aircraft at 8463 m (27,767 ft.) elevation. The image was collected as part of ongoing research into the potential use of remotely sensed data such as SAR for soil-water content and frozen soil monitoring.

#### Objective 3:

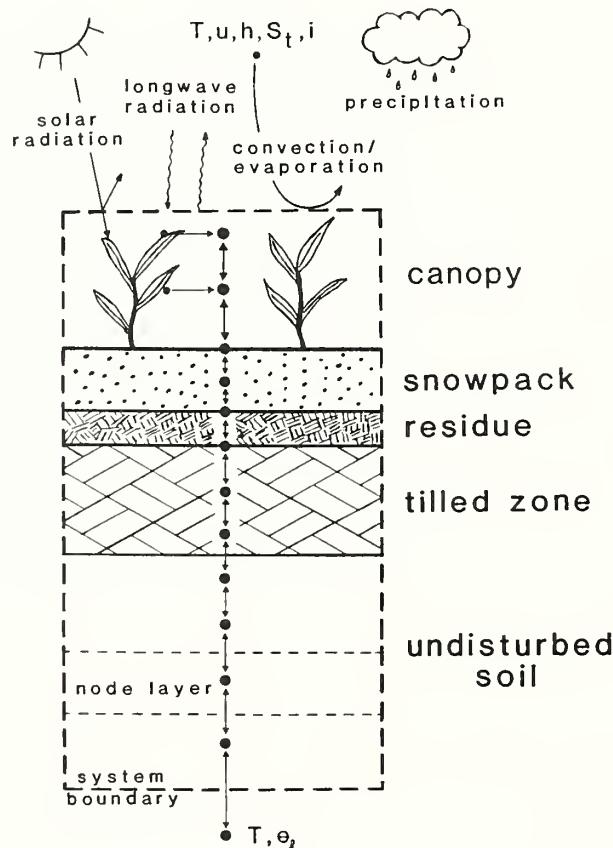
Develop and modify components of hydrologic and atmospheric models to improve the evaluation of land-atmosphere processes and interactions.

## Rationale:

Current models are often inadequate to address global change impacts on hydrologic and land-atmosphere processes. Improved process-oriented models will enable better quantification of water and energy fluxes to, within and from ecosystems under current and predicted future climate scenarios.

## Tasks:

1. Develop and modify model components to improve capabilities and facilitate application of physically based hydrologic simulation models (Boise, Tucson, Durant).



**Figure 7.** Physical description of the system represented by the SHAW model, which simulates the interrelated heat, water and solute transfer through plant cover, snow, residue and soil.

2. Develop an improved snowmelt-runoff model (SRM) that incorporates both degree day and radiation budget techniques

for calculating snowmelt. Use remote sensing to calculate incoming solar radiation at the surface to melt snow and digital elevation data to extrapolate from a point to a complex area (Beltsville).

3. Develop and modify models to account for the effect of management practices - tillage, crop roots, crop canopy, and residue cover on water, energy and gas fluxes (Ft. Collins).
4. Analyze data and develop energy balance models using comprehensive field experiments (Beltsville and Durant).

#### **Objective 4:**

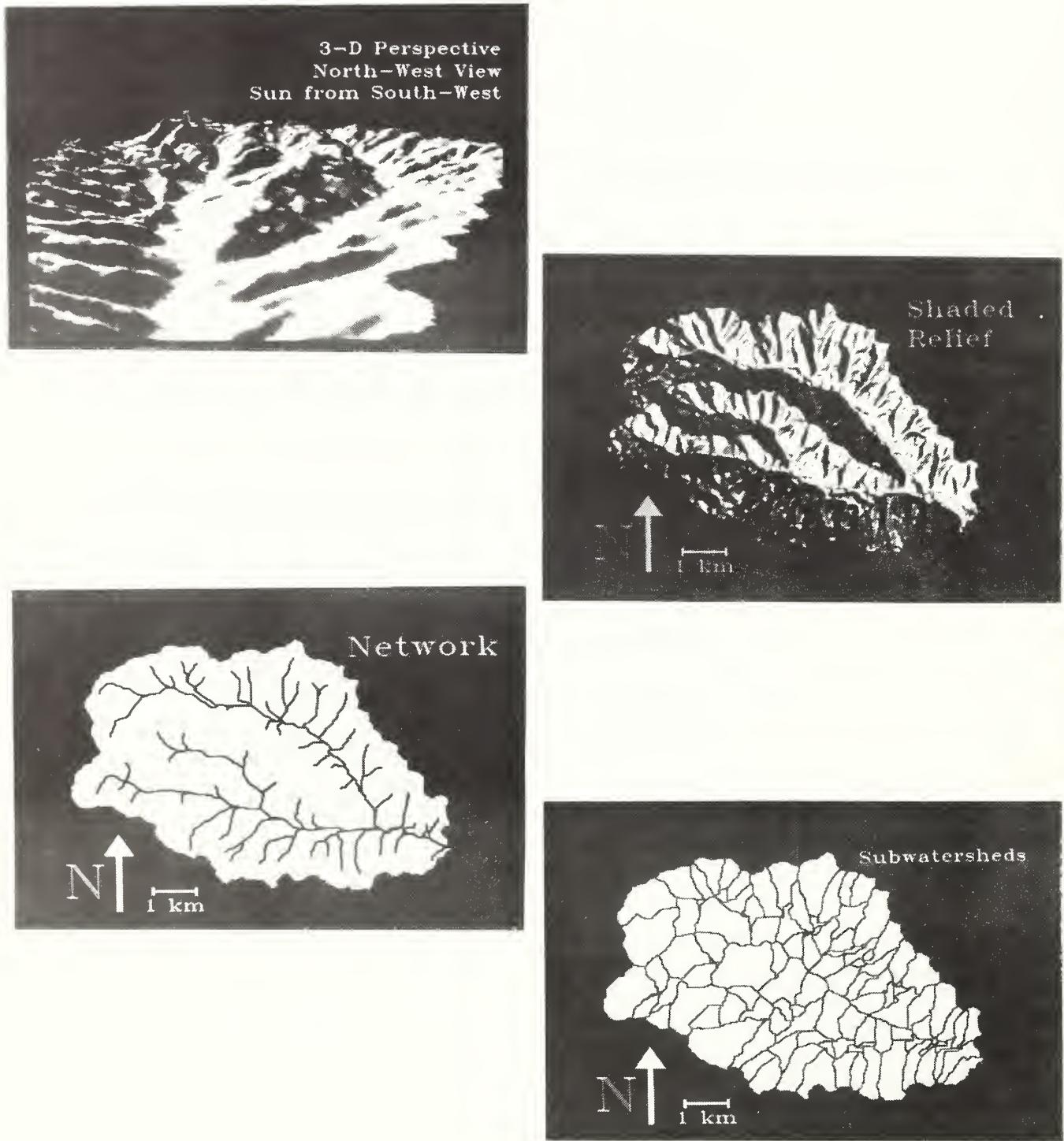
Determine the spatial variability of precipitation and temperature on a watershed scale, their temporal characteristics, and their relationship to atmospheric and topographic influences.

#### **Rationale:**

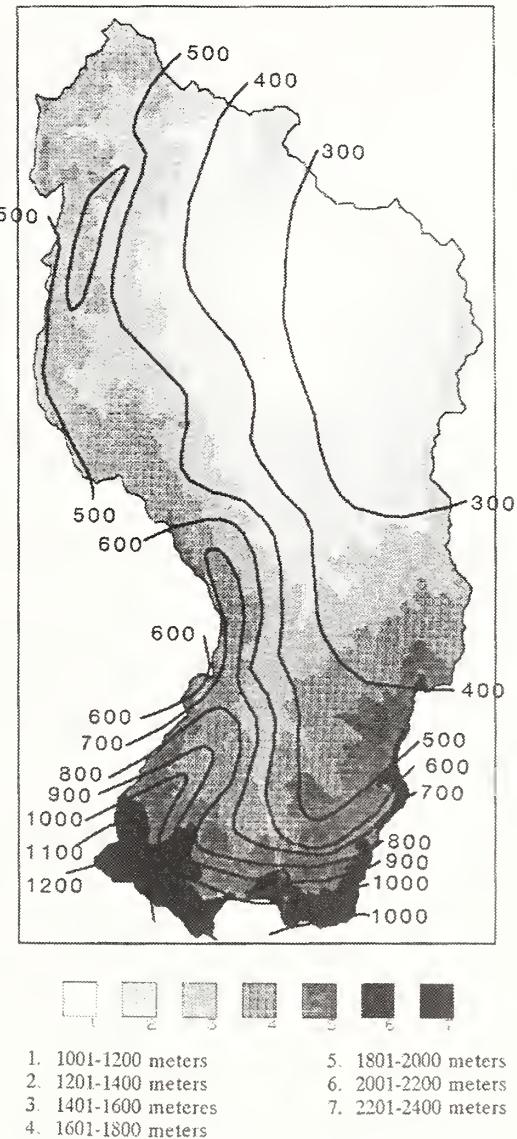
The spatial distribution of precipitation and other weather variables over a watershed are important in determining runoff, reservoir recharge and water management. It is, therefore, important to gain a more complete understanding of spatial and temporal variability, linkages to atmospheric patterns and the potential impact of global change on such variability.

#### **Tasks:**

1. Utilize multivariate statistical techniques to examine the spatial variability of precipitation over distinct regions of the U.S. (the Intermountain and Pacific Northwest, the Great Plains and the Arid Southwest) on different time scales (daily, monthly, seasonally and annually). Identify these spatial patterns with physical landscape features (including elevation, aspect and slope) and their interaction with atmospheric flow through use of appropriate statistical frameworks, geographic information systems (GIS) and remote sensing and image processing systems. From this work, infer induced changes in system response and spatial variability from a perturbed climate system (Boise, Durant and Ft. Collins).



**Figure 8.** Extraction of channel network and drainage basin data from raster digital elevation models (utilizing a geographic information system) for a tributary of the Little Washita Experimental Watershed, Oklahoma. This is an example of the use of new technologies for parameter estimation and system evaluation of hydrologic and atmospheric models: a) 3-dimensional view of watershed; b) shaded relief; c) extracted drainage network; and, d) subwatershed boundaries.



**Figure 9.** Shaded elevation and overlaying mean annual precipitation (mm) contours of the Reynolds Creek Experimental Watershed, Idaho, utilizing a GIS.

2. As part of the WEPP modeling effort, a database of over 1000 National Weather Service climate station records were extracted from the climate data of the United States. These selected stations spaced on a 1 X 1 degree grid will be aggregated to a GCM scale (4 X 7 degree), and precipitation and temperature will be calculated for daily, monthly and annual characteristics. These data could be used for comparison with GCM outputs. Characteristics such as number of wet days by months or season, amount of precipitation and other variables could be used as an indicator of GCM performance (Durant and Tucson).

3. Conduct time series analyses of precipitation and temperature data for the WEPP one degree grid and the aggregated GCM grid databases to determine the temporal dependence structure of the time series at the two spatial scales (Tucson, Durant, Temple and Ft. Collins).

### Objective 5:

Integrate spatial dependence, non-stationarity, natural and anthropogenic climatic variability and orographic effects into existing weather generators.

#### Rationale:

At many locations, long term climatic data are needed to evaluate the effects of projected global change on hydrologic response of watersheds and river basins. Thus, new generators that include non-stationarity and represent spatial dependence are needed.

#### Tasks:

1. Use the existing weather generators such as CLIGEN and USCLIMAT.BAS as a basis for stochastic weather generators that incorporate spatial dependence and non-stationarity (Boise, Durant and Temple).
2. Assess current scientific advancements regarding feedback mechanisms and how they may be relevant to and incorporated into weather generators (Tucson).

### Program Element II:

Use models and scientific methods to estimate the hydrologic effects of global change and to identify potential mitigation and adaptive strategies.

**General Approach:** State-of-the-science models that have been fully tested will be used to estimate the hydrologic effects of global change on agricultural and rangeland productivity. The resulting improvement in understanding the linkages and interactions at different scales will permit quantitative assessment of the effects of global change on the hydrologic system, and the effects of terrestrial hydrology on the global environment.

## **Objective 1:**

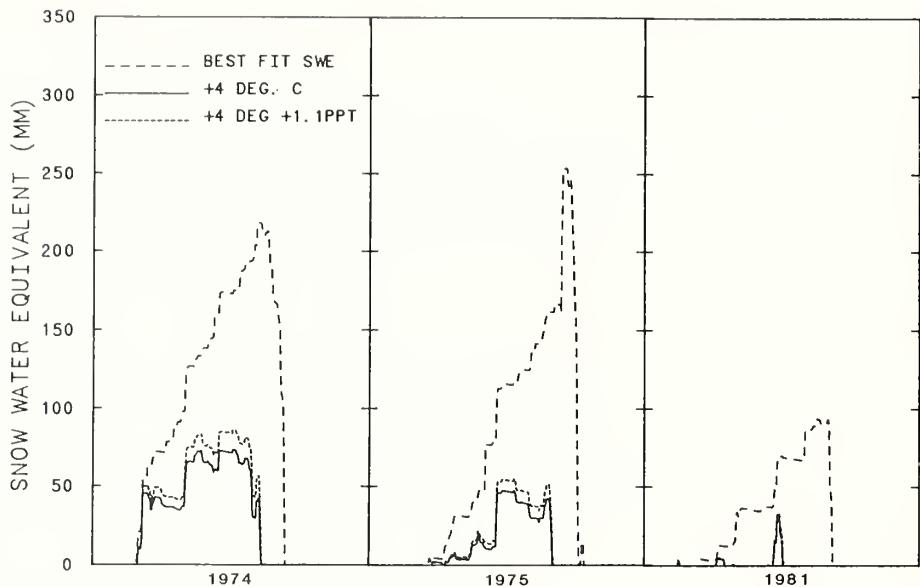
Use hydrologic models and methods to determine the effects of potential global change on all aspects of the hydrologic cycle to, within and from managed ecosystems.

### **Rationale:**

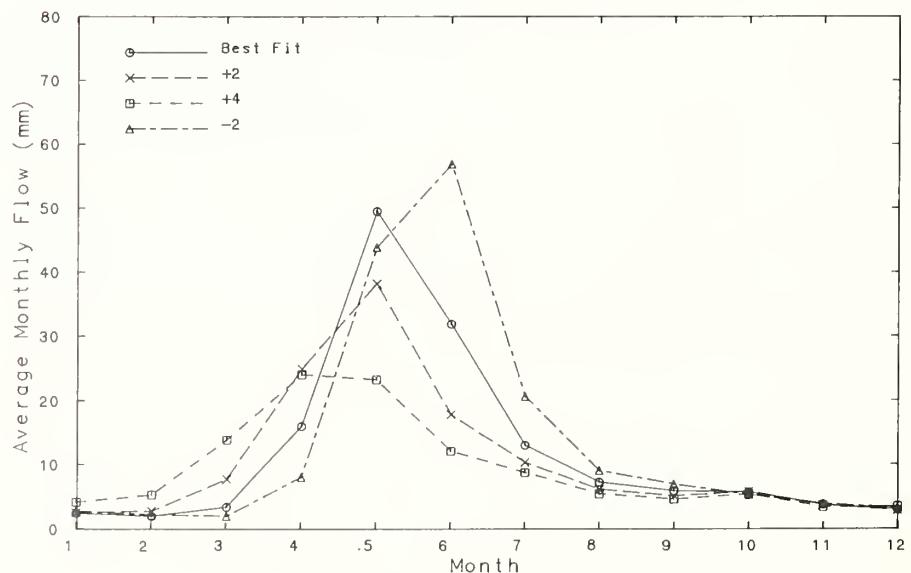
Most global change effects take place over long time periods. Therefore, a methodology is needed to provide estimates of future hydrologic changes. Because hydrologic models simulate processes, they can be used as tools to predict hydrologic responses to various global change scenarios.

### **Tasks:**

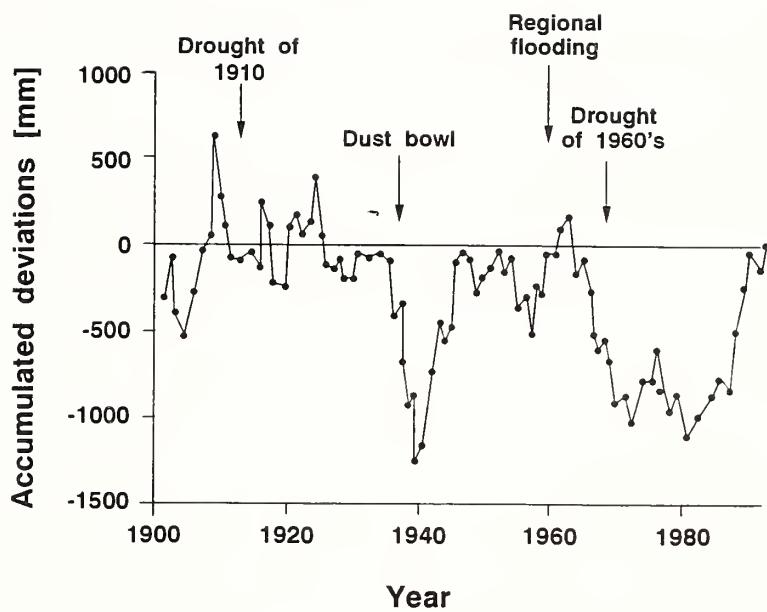
1. Survey existing snowmelt runoff and water supply models and evaluate their performance in simulating streamflow and usefulness for climate change analysis (Beltsville and Boise).
2. Conduct periodic workshops to determine how major snowmelt runoff models are used in climate change analysis and to develop a unified approach for determining hydrologic responses (Beltsville and Boise).
3. Conduct a comparison of the major water supply models for evaluating hydrologic response to climate change on several important western U.S. basins (Beltsville and Boise).
4. Use snowmelt-runoff models to develop hydrologic response scenarios for key basins in various climatic regions of the western United States employing improved General Circulation Model inputs (Beltsville and Boise).
5. Define extended periods of wet and dry conditions from past records for Southern Plains watersheds, determine meteorological characteristics for each of the wet and dry periods and relate them to corresponding watershed response characteristics (Durant).



**Figure 10.** Simulated snow water equivalent utilizing the National Weather Service River Forecast System model (NWSRFS) at a snow observation site on the Lower Willow Creek watershed, Montana. Water years 1974, 1975 and 1981 are shown under normal conditions (best fit),  $4^{\circ}\text{C}$  warming, and  $4^{\circ}\text{C}$  warming plus a 10% increase in precipitation.



**Figure 11.** Simulated average long-term (1974-1984) monthly streamflow for Lower Willow Creek, Montana, under normal conditions (best fit),  $2^{\circ}\text{C}$  warming,  $4^{\circ}\text{C}$  warming and  $2^{\circ}\text{C}$  cooling.



**Figure 12.** Accumulated deviations of annual precipitation for 1901-1989 to identify extended drought and wet periods. Little Washita Basin average, Oklahoma.

### Objective 2:

Interactively utilize natural resource models as a basis for developing mitigation and adaptive strategies to avoid or minimize the negative effects, and optimize the positive effects of global change on managed ecosystems within the global environment.

#### Rationale:

When hydrologic models are used to generate hydrologic response and climate change scenarios in selected basins, a general information base will be available to water resource managers. These managers can then employ appropriate models to generate hydrologic responses for their specific basins and produce management response strategies.

**Tasks:**

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1. Assemble, interpret and distribute results of model classifications, model comparisons, and hydrologic response and climate change scenarios for water resource managers (Beltsville and Boise).
2. Develop techniques to estimate ancillary responses to climate induced changes in soil water, streamflow and other fluxes to assist land and water resource managers. Evaluate effects on stream channels, water quality, erosion, sediment yield, reservoir siltation rates and vegetation (Beltsville, Boise, Durant, Ft. Collins, Temple and Tucson).
3. Develop decision support systems to assist land and water resource managers in selecting the best management strategy from among feasible mitigation alternatives (Boise and Tucson).

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## **Benefits of the Program to Society, Agriculture and Natural Resource Managers**

Research results from the ARS-GCWRA program will enhance the capabilities of resource managers to predict and respond to the impacts of global change on the water cycle, and the productivity of managed ecosystems. Products developed under the climate and hydrology science areas of ARS-GCWRA will take the form of:

- **Models** - to improve estimates of water and energy fluxes to, within and from managed ecosystems at elemental scales up to 10,000 square kilometers as affected by temporal and spatial variability. New water resource models will be developed that are fully compatible with remote sensing and geographic information system technologies.
- **Model derived scenarios** - estimating the effects of potential climate change on water and energy fluxes to, within and from managed ecosystems for a wide variety of climatic conditions, including droughts, at elemental scales up to 10,000 square kilometers.

- **Adaptive strategies** - for mitigating global climate change effects on agricultural systems which may be negatively affected by change, and enhancing and optimizing climate change effects on those systems positively affected.
- **Long term databases** - of hydrologic and climate measurements that will be accessible to outside researchers.

These products will benefit society by improving the present and future management of the water cycle. Improvements in hydrologic predictions and the development of mitigation, adaptation and optimal use strategies will help insure that adequate water is available in the future for sustained agricultural production, municipal and industrial water supplies, hydro-power, and in-stream uses such as recreation, fisheries, flows to bays and estuaries, and water quality.

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## Current ARS Research Capabilities as Related to ARS-GCWRA

The ARS has primary responsibility for developing the knowledge base required to manage cropland and rangeland ecosystems to meet and sustain human needs. The Agency is a leader in the development and application of physically-based models for energy and water transfer in agricultural and rangeland systems. Natural resource models developed by the ARS include: AGNPS, CREAMS, EPIC, ERYHM, GLEAMS, KINEROS, MUSLE, Opus, RUSLE, RZWQM, SHAW, SPAW, SPUR, SRM, SWRRB, USLE, and WEPP. These models simulate a wide range of natural processes including water balance, soil erosion and chemical transport, and have been used to study and estimate the effects of management changes on water use efficiency, productivity, and the fate of water, nutrients and pesticides at field scale. Other small watershed and basin scale models predict water, solute, and sediment movement through the channel, groundwater and impoundments of natural and managed ecosystems. Water supply forecast models simulate the accumulation and melt of snow utilizing remotely sensed measurements at fixed time intervals as input. Many of these models will serve as a basis within which new knowledge can be incorporated and as a resource to aid in projecting the effects of global change on the partitioning of water and energy in natural and managed ecosystems.

Long-term hydrologic data are essential to provide a base-line from which change can be measured as well as to supply input for physically-based models. The ARS has several hundred experimental watersheds operated by 14 research centers, with data records exceeding 50 years at several locations. These experimental watersheds and their databases are currently being used to enhance our understanding of hydrologic processes over a range of scales from small plots to large watersheds (<1 meter to 637 square kilometers). The spatial and temporal aspects of hydrologic processes at these different scales are also being investigated. Data have been collected for environmental variables such as precipitation, streamflow, temperature, solar radiation, soil water, vegetation, evaporation, plant-water use, snow accumulation and melt, and groundwater recharge. Of particular importance to the global change issue is the emphasis that has been placed on the soil-plant-atmosphere interface and the fluxes of water and energy through this system. The ARS's unique laboratories, databases and commitment place it in a strong position to assess and investigate the effects of global climate change on managed ecosystems.

The most important resource of ARS is its scientists. They have internationally recognized expertise in areas relevant to assessing the effects of global change on managed ecosystems: remote sensing, hydrologic modeling, meteorology, soil physics, engineering, plant physiology and ecology, water chemistry and sedimentation. Many ARS scientists have made exemplary contributions to hydrology, water resources, soil and water relations, remote sensing and related fields. Agency scientists are among the world leaders at carrying out watershed studies of hydrologic processes. ARS watershed data, representing numerous land resource areas in various climatic zones of the United States, is a unique international resource valuable in global change studies.

## Definition of Acronyms Used

### Federal Agencies and Programs

**ARS** - Agricultural Research Service  
**ARS-GCRP** - Agricultural Research Service - Global Change Research Program  
**ARS-GCWRA** - Agricultural Research Service - Global Change Water Resources and Agriculture  
**BLM** - Bureau of Land Management  
**BOR** - Bureau of Reclamation  
**CEES** - Committee on Earth and Environmental Sciences  
**DOE** - Department of Energy  
**FS** - Forest Service  
**NASA** - National Aeronautics and Space Administration  
**NCAR** - National Center for Atmospheric Research  
**NOAA** - National Oceanic and Atmospheric Administration  
**NWS** - National Weather Service  
**SCS** - Soil Conservation Service  
**USDA** - United States Department of Agriculture  
**USDC** - United States Department of Commerce  
**USDI** - United States Department of Interior  
**US/GCRP** - United States Global Change Research Program Plan  
**USGS** - United States Geological Survey

### Natural Resource Models

**AGNPS** - Agricultural Non-point Pollution Source Model  
**CREAMS** - Chemicals, Runoff and Erosion from Agricultural Management Systems  
**EPIC** - Erosion Prediction Impact Calculator  
**ERYHM** - Ekalaka Rangeland Yield and Hydrology Model  
**GCM** - General Circulation Model  
**GLEAMS** - Groundwater Loading Effects on Agricultural Management Systems  
**KINEROS** - Kinematic Runoff and Erosion Model  
**MUSLE** - Modified Universal Soil Loss Equation  
**RUSLE** - Revised Universal Soil Loss Equation  
**RZWQM** - Root Zone Water Quality Model  
**SHAW** - Simultaneous Heat and Water Model  
**SPAW** - Soil, Plant, Air and Water Model  
**SPUR** - Simulation of Production and Utilization of Rangelands  
**SRM** - Snowmelt Runoff Model  
**SWRRB** - Simulator for Water Resources in Rural Basins  
**USLE** - Universal Soil Loss Equation  
**WEPP** - Water Erosion Prediction Project

### Others

**CFC** - Chlorofluorocarbons  
**GIS** - Geographic Information System

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